www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

JOURNAL OF PLANT PROTECTION RESEARCH Vol. 54, No. 2 (2014)

DOI: 10.2478/jppr-2014-0029

The effect of soil mulching with organic mulches, on weed infestation in broccoli and tomato cultivated under polypropylene fibre, and without a cover

*Edyta Kosterna**

Department of Vegetable Crops, Siedlce University of Natural Sciences and Humanities, Prusa 14, 08–110 Siedlce, Poland

Received: October 11, 2013
Accepted: May 26, 2014

Abstract: An investigation was done on the effect of different types of organic mulches that were applied in form of straw to the soil mulching process, on the weed infestation, number, and fresh mass of weeds in broccoli cv. Milady F_1 (*Brassica oleracea* L. var. *italica* Plenck) and tomato cv. Polfast F_1 (*Lycopersicon esculentum* Mill.) grown under polypropylene fibre as a covering, or grown without a covering. The different types of organic straw mulches were: rye (*Secale cereale* L.), corn (*Zea mays* L.), rape (*Brassica napus* L. subsp. *napus*), and buckwheat (*Fagopyrum esculentum* Moench.). All the organic mulches were applied at a dose of 10 t/ha. The effect of the mulches was compared to a control plot which had no mulch. The type of organic mulch applied to the soil mulching process influenced species composition, number, and fresh mass of weeds. This effect could be the result of the properties of the mulch (colour, structure, etc.) or the allelopathic effect on the germination and growth of individual weeds species. Irrespective of the investigated factors, 24 and 25 weeds species, respectively, were observed immediately after cover removal and before broccoli and tomato harvest. In the first date of estimation *Chenopodium album* L., *Echinochloa crus-galli* (L.) P. Beauv., *Fallopia convolvulus* (L.) Á. Löve, *Stellaria media* (L.) Vill., and *Viola tricolor* L. dominated, however, before the vegetables were harvested *Ch. album, V. tricolor, Veronica arvensis* L., and *E. crus-galli* dominated. An application of polypropylene fibre contributed to an increase in the number and fresh mass of weeds in both vegetables in the first date of estimation (after cover removal). During this period, vegetables cannot compete with weeds. It is important to note, though, that before the vegetables were harvested, a decrease was found in the number and fresh mass of weeds in the covered plots. The most efficient weed limiter, both after cover removal and also before the broccoli and tomatoes were harvested, was buckwheat and rye straw, respectively.

Key words: broccoli, organic mulch, polypropylene fibre, tomato, weed infestation

Introduction

In the integrated and ecological agriculture systems, more attention is being paid to what can be the longest possible period of soil coverage with plant mulches and mulches from straw after cereal grain harvest (Liebman and Davis 2000; Bàrberi 2002; Economou *et al*. 2002; Campiglia *et al*. 2010; Bittencourt *et al*. 2013). When straw from plants is left in the field as mulch, erosion is reduced, and the biological activity of the soil increases, both of which efficiently inhibit the growth of weeds (Hembry and Davies 1994; Teasdale and Mohler 2000; Duppong *et al*. 2004; Grassbaugh *et al*. 2004; Rogers *et al*. 2004; Ramakrishna *et al*. 2006). Organic mulch can block light to the soil surface, reducing the germination and growth of weeds (Anyszka and Dobrzański 2008). Infestation is limited by both the mechanical effect of an application of mulch (Hembry and Davies 1994), and by the allopathic effect of chemical compounds contained in the tissue of plant mulches (Creamer *et al*. 1996; Smeda and Weller 1996). According to Jodaugienė *et al*. (2006), a positive effect of mulch is particularly visible in the period of intensive weed germination. In the study by Zagaroza (2003), how efficient the mulch was depended on the thickness of the mulch layer on the soil surface.

There is a limited number of studies pertaining to the application of organic mulch in the cultivation of vegetables. Studies dealing with the application of straw mulches in bean and onion cultivation were carried out by Jodaugienė *et al*. (2006). Radics and Bognár (2004) and Grassbaugh *et al*. (2004) examined mulches used with tomatoes, Döring *et al*. (2005) with potatoes, whereas Sinkevičienė *et al*. (2009) investigated the effect of mulches in onions, red beets, cabbages, and potatoes.

The use of a plastic cover significantly influenced the growth of crop plants and also caused increased weed infestation. Mechanical and chemical weed control under the plastic covers is difficult. Limiting the growth of weeds under the covers could be achieved by applying different types of mulch. Simultaneous soil mulching and plant covering can positively influence vegetable yield.

The study aimed to determine the effect of soil mulching with organic mulch on the weeds infestation, number,

*Corresponding address:
edyta.kosterna@uph.edu.pl

and fresh mass of weeds in broccoli and tomato cultivation under a polypropylene fibre cover, compared to using no cover.

Materials and Methods

The experiment was carried out between 2010 and 2012 at the Experimental Farm in Zawady, which is located in central-eastern Poland (52°03′N, 22°33′E), 115 km east of Warsaw. According to the international system of FAO classification, the soil was classified as a Luvisol (LV) [World Reference Base for Soil Resources 1998].

The experiment was established in a split-block design with three replicates. Effects of the following factors were investigated: the plant coverings (without any cover, under a polypropylene fibre cover), and the type of organic mulch with straw applied as soil mulching [rye (*Secale cereale* L.), corn (*Zea mays* L.), rape (*Brassica napus* L. subsp. *napus*), buckwheat (*Fagopyrum esculentum* Moench.)]. The effect of using mulch was compared to a control plot in which mulch was not used. The effect of the examined factors on the weed infestation, as well as number and fresh mass of weeds in broccoli cv. Milady F_1 (*Brassica oleracea* L. var. *italica* Plenck) and tomato cv. Polfast F_1 (*Lycopersicon esculentum* Mill.) was investigated.

A reason for selecting the specific cultivars that were used in the study was because they were early and also useful for cultivation in the open field. Broccoli cv. Milady F_1 is characterised as having a high mass of heads and as being of very good quality. It is also resistant to *Peronospora parasitica* as well as *Erwinia* spp., and *Pseudomonas* spp. Tomato cv. Polfast F_1 is characterised as having an average fruit mass which are of very good quality, and as having a high content of dry matter and extract. This cultivar produces a high yield even in low air temperatures. It is also more resistant to diseases compared to other tomato cultivars.

The field for cultivation of the vegetables was prepared in accordance with the principles of proper agricultural technology. Broccoli and tomato seedlings were produced in non-heated and heated greenhouse, respectively, in the traditional way of growing the vegetables.

Directly before the seedlings were planted, a particular type of organic mulch at a dose of 10 t/ha was applied. Mulch with rye, rape, and buckwheat straw was in rather long (30–40 cm) pieces. These pieces were crumbled up, so it would be easy to spread them on the field. However, mulch with corn straw was chopped up into short pieces (20–30 cm). The thickness of the mulch layer depended on the type of mulch. In the case of rye and rape straw, the thickness of the mulch layer amounted, on average, to 7–8 cm. In the case of corn straw, the mulch layer amounted to about 5 cm, however for buckwheat straw the average was 8–10 cm.

Broccoli seedlings were planted in successive years of the study on the 19th, 18th, and 23rd of April, at a spacing of 50 × 50 cm. Tomato seedlings were planted, respectively, on 20th, 16th, and the 14th of May, at a spacing of 60 × 40 cm. After planting suitable combinations of seedlings, they were covered with polypropylene fibre Pegas Agro 17 UV. The covers were removed after four and three weeks from broccoli and tomato, respectively.

The effect of the examined factors on weed infestation was estimated twice each year. The primary infestation was performed in the initial period of vegetable growth, directly after cover removal, which meant the third 10 days of May in broccoli cultivation, and the second 10 days of June in tomato cultivation. After that, manual weeding was performed. The secondary infestation in broccoli cultivation was performed before harvesting, which meant the third 10 days of June, and in tomato cultivation at the beginning of the fruit harvest, which meant the third 10 days of July. Weed infestation was determined by the quantitative-weighing method. This method entailed determining the number of individual weeds species and their fresh mass in each plot. Samples were taken from an area of a selected 0.5 m square at two randomly selected places in each plot. The weight of the weeds was expressed per 1 m^2.

The results were statistically analysed by means of the analysis of variance following the mathematical model for the split-block design. Significance of differences was determined by the Tukey test at the significance level of $p = 0.05$.

Results and Discussion

The effect of covering and mulching on the weed composition

The species composition of weed communities depends largely on soil and climate conditions (Zarzecka and Gąsiorowska 2001) and agrotechny treatments (Pszczółkowski 2003a). In this study, after cover removal from broccoli cultivation, 19 weed species made up of 16 annuals and 3 perennials, were noted. In tomato cultivation, 22 weed species, including 20 annuals and 2 perennials were observed, mostly characteristic for vegetable crops (Tables 1–2). Irrespective of the examined factors, the dominant species among the annuals were *Chenopodium album* L., *Echinochloa crus-galli* (L.) P. Beauv., *Fallopia convolvulus* (L.) Á. Löve, *Stellaria media* (L.) Vill., and *Viola arvensis* L. However, among the perennials, the most common weed was *Elymus repens* (L.) Gould. The composition of the weed species was similar to that found in the study carried out in mid-east Poland (Zarzecka and Gugała 2005). Of the total number of species in the broccoli cultivation experiment, *Myosotis arvensis* (L.) Hill., *Polygonum persicaria* L., *Conyza canadensis* (L.) Cronquist., *Raphanus raphanistrum* L., and *Anthemis arvensis* L. were not observed. In tomato cultivation, *Centaurea cyanus* L. was not observed. According to Yordanova and Shaban (2007), organic mulch, irrespective of the mulch layer on the soil surface, did not provide good weed control, especially against the perennial weeds.

In this study, the application of a polypropylene fibre cover caused increased infestation in the initial period of vegetable growth compared with plots without cover (Table 1–2). In analysing the occurrence of annual weeds, it was found that in broccoli cultivation, the number of *E. crus-galli* under cover was four times greater, and the

Table 1. The species composition of weeds (plant/m^2) after cover removal in broccoli cultivation (the mean for 2010–2012)

Kind of straw mulch	The control			Rye			Corn			Rape			Buckwheat			The mean		
Cultivation	A*	B**	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean
Chenopodium album L.	72.9	71.1	72.0	3.6	40.9	22.3	40.9	71.1	56.0	39.1	78.2	58.7	21.3	44.4	32.9	35.6	61.1	48.4
Echinochloa crus-galli (L.) P. Beauv.	28.4	65.8	47.1	0.0	37.3	18.7	3.6	32.0	17.8	5.3	30.2	17.8	3.6	12.4	8.0	8.2	35.5	21.9
Fallopia convolvulus (L.) Á. Löve	32.0	44.4	38.2	10.7	17.8	14.3	16.0	28.4	22.2	7.1	19.6	13.4	5.3	12.4	8.8	14.2	24.5	19.4
Stellaria media (L.) Vill.	42.7	42.7	42.7	5.3	5.3	5.3	3.6	14.2	8.9	12.4	23.1	17.8	5.3	19.6	12.5	13.9	21.0	17.5
Brassica napus L. subsp. *napus*	0.0	0.0	0.0	0.0	8.9	4.5	0.0	16.0	8.0	26.7	40.9	33.8	0.0	0.0	0.0	5.3	13.2	9.3
Tripleurospermum maritimum L.	7.1	14.2	10.7	3.6	1.8	2.7	8.9	17.8	13.4	5.3	3.6	4.5	8.9	8.9	8.9	6.8	9.3	8.1
Viola arvensis L.	3.6	14.2	8.9	0.0	12.4	6.2	12.4	21.3	16.9	0.0	7.1	3.6	3.6	0.0	1.8	3.9	11.0	7.5
Capsella bursa-pastoris (L.) Med.	12.4	19.6	16.0	5.3	1.8	3.6	8.9	7.1	8.0	3.6	8.9	6.3	0.0	1.8	0.9	6.0	7.8	6.9
Veronica arvensis L.	3.6	30.2	16.9	3.6	0.0	1.8	5.3	3.6	4.5	5.3	7.1	6.2	0.0	0.0	0.0	3.6	8.2	5.9
Centaurea cyanus L.	3.6	3.6	3.6	0.0	1.8	0.9	7.1	0.0	3.6	7.1	1.8	4.5	0.0	0.0	0.0	3.6	1.4	2.5
Fagopyrum esculentum Moench.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	8.9	6.3	0.7	1.8	1.3
Amaranthus retroflexus L.	0.0	1.8	0.9	0.0	1.8	0.9	0.0	3.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.7
Geranium pusillum L.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.4
Sinapis arvensis L.	0.0	0.0	0.0	1.8	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2
Vicia sativa L.	0.0	0.0	0.0	1.8	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2
Galium aparine L.	0.0	0.0	0.0	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2
Number of annual species	9	10	10	8	11	14	9	11	12	9	10	10	7	7	8	13	14	16
Elymus repens (L.) Gould.	24.9	83.6	54.3	33.8	44.4	39.1	24.9	35.6	30.3	10.7	23.1	16.9	5.3	35.6	20.5	19.9	44,5	32.2
Cirsium arvense (L.) Scop.	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.9	1.8	0.0	0.9	0.0	0.0	0.0	0.7	0,0	0.4
Taraxacum officinale F.H. Wigg.	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0,4	0.2
Number of perennial species	1	2	2	1	1	1	2	1	2	2	1	2	1	1	1	2	2	3
Total number of species	10	12	12	9	12	15	11	12	14	11	11	12	8	8	9	15	16	19

*without cover; **under polypropylene fibre

Table 2. The species composition of weeds (plant/m^2) after cover removal in tomato cultivation (the mean for 2010–2012)

Kind of straw mulch	The control			Rye			Corn			Rape			Buckwheat			The mean		
Cultivation	A*	B**	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean
Viola arvensis L.	17.8	21.3	19.6	14.2	19.6	16.9	12.4	33.8	23.1	29.3	35.6	32.5	47.1	63.1	55.1	24.2	34.7	29.5
Echinochloa crus-galli (L.) P. Beauv.	44.4	53.3	48.9	1.8	16.9	9.4	2.7	14.2	8.5	16.0	17.8	16.9	6.2	17.8	12.0	14.2	24.0	19.1
Chenopodium album L.	21.3	29.3	25.3	3.6	11.6	7.6	18.7	22.2	20.5	21.3	36.4	28.9	11.6	12.4	12.0	15.3	22.4	18.9
Fallopia convolvulus (L.) Á. Löve	17.8	26.7	22.3	16.9	22.2	19.6	19.6	20.4	20.0	15.1	20.4	17.8	9.8	11.6	10.7	15.8	20.2	18.0
Tripleurospermum maritimum L.	10.7	21.3	16.0	3.6	10.7	7.2	8.9	9.8	9.4	3.6	5.3	4.5	20.4	19.6	20.0	9.4	13.3	11.4
Veronica arvensis L.	12.4	12.4	12.4	2.7	6.2	4.5	14.2	21.3	17.8	0.0	21.3	10.7	0.0	0.0	0.0	5.9	12.2	9.1
Capsella bursa-pastoris (L.) Med.	1.8	12.4	7.1	1.8	4.4	3.1	1.8	8.9	5.4	4.4	5.3	4.9	2.7	7.1	4.9	2.5	7.6	5.1
Geranium pusillum L.	1.8	3.6	2.7	0.0	0.0	0.0	1.8	6.2	4.0	0.0	12.4	6.2	0.0	3.6	1.8	0.7	5.2	3.0
Amaranthus retroflexus L.	0.0	0.0	0.0	0.0	3.6	1.8	0.0	1.8	0.9	1.8	10.7	6.3	1.8	3.6	2.7	0.7	3.9	2.3
Brassica napus L. subsp. *napus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	10.7	9.8	0.0	0.0	0.0	1.8	2.1	2.0
Fagopyrum esculentum Moench.	0.0	0.0	0.0	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	5.3	7.1	6.2	1.1	1.8	1.5
Myosotis arvensis (L.) Hill.	2.7	1.8	2.3	0.0	0.0	0.0	2.7	3.6	3.2	0.0	3.6	1.8	0.0	0.0	0.0	1.1	1.8	1.5
Sinapis arvensis L.	0.0	0.0	0.0	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7	5.4	0.0	2.5	1.3
Vicia sativa L.	0.0	1.8	0.9	0.0	1.8	0.9	0.0	5.3	2.7	0.0	0.0	0.0	0.0	3.6	1.8	0.0	2.5	1.3
Stellaria media (L.) Vill.	1.8	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.5	0.0	3.6	1.8	1.8	3.6	2.7	0.9	1.4	1.2
Polygonum persicaria L.	0.0	1.8	0.9	0.9	3.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.9	0.5	1.1	0.8
Conyza canadensis (L.) Cronquist.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	5.3	3.6	0.0	0.0	0.0	0.4	1.1	0.8
Raphanus raphanistrum L.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.9	1.8	0.0	0.9	0.4	0.4	0.4
Galium aparine L.	0.0	0.0	0.0	2.7	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.3
Anthemis arvensis L.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.9	0.0	0.0	0.0	0.4	0.0	0.2
Number of annual species	10	11	12	9	12	13	10	11	12	10	14	15	11	12	14	18	18	20
Elymus repens (L.) Gould.	0.0	1.8	0.9	10.7	19.6	15.2	0.0	3.6	1.8	0.0	7.1	3.6	0.0	0.0	0.0	2.1	6.4	4.3
Taraxacum officinale F.H. Wigg.	3.6	5.3	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.1	0.9
Number of perennial species	1	2	2	1	1	1	0	1	1	0	1	1	0	0	0	2	2	2
Total number of species	11	13	14	10	13	14	10	12	13	10	15	16	11	12	14	20	20	22

*without cover; **under polypropylene fibre

number of *Ch. album* was almost two times that of plots without cover. In tomato cultivation, the differences were lower. The number of *V. arvensis* under cover was higher by 43%, and the number of *E. crus-galli* was higher by 69% than plots without cover. In comparing the intensity of perennial weed infestation, it was found that the number of *E. repens* under cover in broccoli cultivation was two times greater, and in tomato it was three times greater, than in plots without cover.

Irrespective of the type, organic mulch limited infestation in both vegetable species (Tables 1–2). Mulch with rye straw reduced the occurrence of *Ch. album*, *S. media* and *V. arvensis* the most. *F. convolvulus* was reduced the most by buckwheat straw, and *E. crus-galli* was reduced the most by corn and buckwheat straw. Among the investigated types of mulch, buckwheat and rape straw limited *E. repens*.

There was a total of 20 weed species noted before the broccoli and tomatoes were harvested. The weed species included 17 annual and 3 perennial (Tables 3–4). Irrespective of vegetable type, the dominant weed species among annuals were *Ch. album*, *V. arvensis*, and *Veronica arvensis* L., *E. crus-galli*. Among perennials, as was similar to the first date that estimations were done, the dominant weed species was *E. repens*. The species *Ch. album* occurs most frequently in broccoli after the cover is removed. The number of *Ch. album* decreased almost three-fold, and *V. arvensis* in tomato decreased two-fold at the estimation which was done before the vegetable harvest (Tables 1–4). Of the total number of species in this estimation date, we did not observe *F. esculentum* or *Geranium pusillum* L. in broccoli cultivation. In tomato cultivation, we did not observe the presence of *Thlaspi arvense* L., *Vicia sativa* L., or *Galium aparine* L.

Before vegetable harvest, crop infestation in the plots covered with polypropylene fibre was lower than in the plots without cover (Tables 3–4).

Infestation was lower but still visible, as a result of soil mulching before harvesting the vegetables (Tables 3–4). *Ch. album* and *V. arvensis* was most limited by mulch with buckwheat straw. *Veronica arvensis* was most limited by mulch with rye and rape straw. *E. crus-galli* was most limited by mulch with rye straw. Investigations by Jodaugienė *et al*. (2006) showed that the mulching of soil with various organic mulches is particularly important in the first part of summer. According to the authors, in the second part of summer, weed emergence is weaker in comparison with what occurs in spring and early summer. This means that mulch has less influence later in the summer.

The effect of covering and mulching on the total number of weeds

This study's results indicate the significant influence that plant covering and the type of organic mulch applied to soil mulching has on the number of weeds in both cultivated vegetables immediately after cover removal (Table 5). The covering with polypropylene fibre increased the number of weeds in this period in broccoli, on average, by 119.1 no./m^2 and in tomato by 66.5 no./m^2 compared to plots without cover. A study by Pszczółkowski (2003b) revealed that good thermal conditions under covers are favourable not only for crop plants but also for weeds. This was confirmed in studies by Wierzbicka (1995) and Roztropowicz and Lutomirska (1997). The number of weeds in the covered plots was much higher than in plots without cover. According to Roztropowicz and Lutomirska (1997), higher soil temperature and air saturated with water vapour favour weed development; especially the development of the thermophilic species.

Irrespective of the covering, all the mulch types applied in the experiment significantly reduced the number of weeds in broccoli. This was confirmed by a study by Jodaugienė *et al*. (2006), in which the number of weeds per 1 m^2 in full vegetation ranged from 289.0 to 522.5 in mulched soil; however, 1,378.9 weeds occurred in soil without mulch. In a study by Mohtisham *et al*. (2013), straw mulch reduced the number of germinating weeds by half compared to a control without mulch. Similarly, in a study by Radics and Bognar (2004), mulching with straw and grass significantly limited weed germination compared to plots without mulch. In this study, we also found significantly fewer weeds in plots with rye and buckwheat straw compared to mulch with corn and rape straw.

In the tomato cultivation without cover, the control plot without mulch had the most weeds. Mulch with rye straw significantly limited infestation compared to plots mulched with the remaining types of mulch. In plots with corn straw, there were significantly fewer weeds than in plots with buckwheat straw. In tomato cultivation under cover there were significantly less weeds noted on the mulch with rye straw. It was also found that corn straw mulch significantly reduced weed infestation compared to rape straw and the control plot without mulch. In the study by Jodaugienė *et al*. (2006), among all organic mulches, the mulch that limited weed germination the most at the beginning of summer (3.5–14.1 times) was straw. Straw mulch's favourable effect on the limiting of weeds infestation was also confirmed in the studies by Petersen and Röver (2005) and Ramakrishna *et al*. (2006). The weed-suppressing effect of straw mulch reported in studies, can also result from a limited amount of light reaching the soil surface. According to Weber and Hryńczuk (2005) [in Klümper *et al*. (1996)], germination of some weed species depends on the so-called light reaction which stimulates plant emergence. Cardina *et al*. (1991) and Mohler and Teasdale (1993) claim that lack of light makes weeds remain dormant in the top soil layer, and as a result, no infestation of crop plants takes place. In their studies, Döring *et al*. (2005) found no significant influence of straw mulching on the number of weeds. According to the authors, the doses of straw they examined (1.25 t/ha, 2.5 t/ha, 5 t/ha) neither reduced nor enhanced weed infestation significantly. They attributed it mainly to the small amounts of straw applied. Hembry and Davies (1994) found that weed growth still occurred at 20 t/ha of straw mulch, although there were fewer weeds.

Before the harvesting of the vegetables, a significantly lower number of weeds was found in plots covered with polypropylene fibre (Table 6). The difference amounted to 21.2 no./m^2 for broccoli and 31.6 no./m^2 for tomato. In broccoli cultivation without cover, there were significant-

Table 3. The species composition of weeds (plant/m^2) before broccoli harvest (the mean for 2010–2012)

Kind of straw mulch	The control			Rye			Corn			Rape			Buckwheat			The mean		
Cultivation	A*	B**	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean
Chenopodium album L.	12.4	12.4	12.4	18.7	19.6	19.2	24.9	13.3	19.1	22.2	16.0	19.1	17.8	15.1	16.5	19.2	15.3	17.3
Viola arvensis L.	12.4	14.2	13.3	23.1	7.1	15.1	21.3	9.8	15.6	8.9	5.3	7.1	30.2	8.0	19.1	19.2	8.9	14.1
Veronica arvensis L.	28.4	17.8	23.1	12.4	8.0	10.2	8.9	12.4	10.7	14.2	7.1	10.7	7.1	5.3	6.2	14.2	10.1	12.2
Fallopia convolvulus (L.) Á. Löve	8.9	12.4	10.7	14.2	7.1	10.7	7.1	9.8	8.5	10.7	5.3	8.0	3.6	8.0	5.8	8.9	8.5	8.7
Setaria viridis (L.) P. Beauv.	17.8	10.7	14.3	1.8	1.8	1.8	7.1	3.6	5.4	17.8	8.9	13.4	1.8	8.9	5.4	9.3	6.8	8.1
Echinochloa crus-galli (L.) P. Beauv.	3.6	5.3	4.5	6.2	0.0	3.1	1.8	0.9	1.4	3.6	5.3	4.5	1.8	7.1	4.4	3.4	3.7	3.6
Anthemis arvensis L.	5.3	7.1	6.2	0.0	0.0	0.0	3.6	3.6	3.6	1.8	5.3	3.6	3.6	1.8	2.7	2.9	3.6	3.3
Capsella bursa-pastoris (L.) Med.	3.6	5.3	4.5	2.7	1.8	2.3	5.3	3.6	4.5	3.6	0.0	1.8	0.0	0.0	0.0	3.0	2.1	2.6
Erodium cicutarium (L.) L. Her.	1.8	3.6	2.7	1.8	0.0	0.9	5.3	1.8	3.6	1.8	1.8	1.8	3.6	3.6	3.6	2.9	2.2	2.6
Tripleurospermum maritimum L.	3.6	3.6	3.6	1.8	0.0	0.9	0.0	4.4	2.2	2.7	1.8	2.3	3.6	2.7	3.2	2.3	2.5	2.4
Centaurea cyanus L.	1.8	0.0	0.9	0.9	0.0	0.5	1.8	2.7	2.3	0.9	1.8	1.4	0.0	0.0	0.0	1.1	0.9	1.0
Stellaria media (L.) Vill.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.9	3.6	1.8	2.7	1.1	0.4	0.8
Myosotis arvensis (L.) Hill.	0.0	0.0	0.0	1.8	3.6	2.7	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	0.7
Thlaspi arvense L.	0.0	0.0	0.0	0.9	0.0	0.5	3.6	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.5
Amaranthus retroflexus L.	0.0	0.0	0.0	1.8	2.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.5
Vicia sativa L.	0.0	0.0	0.0	3.6	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.4
Galium aparine L.	0.0	0.0	0.0	0,0	0.0	0.0	0.0	0.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Number of annual species	11	10	11	14	8	14	11	13	14	12	10	12	10	10	10	16	15	17
Elymus repens (L.) Gould.	0.0	3.6	1.8	0.0	8.9	4.5	0.0	4.4	2.2	1.8	0.0	0.9	1.8	0.0	0.9	0.7	3.4	2.1
Taraxacum officinale F.H. Wigg.	0.0	0.0	0.0	1.8	0.0	0.9	3.6	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.6
Equisetum arvense L.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.8	1.4	0.0	0.0	0.0	0.2	0.4	0.3
Number of perennial species	0	1	1	1	1	2	1	1	2	2	1	2	1	0	1	3	2	3
Total number of species	11	11	12	15	9	16	12	14	16	14	11	14	11	10	11	19	17	20

*without cover; **under polypropylene fibre

Table 4. The species composition of weeds (plant/m^2) before tomato harvest (the mean for 2010–2012)

Kind of straw mulch	The control			Rye			Corn			Rape			Buckwheat			The mean		
Cultivation	A*	B	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean	A	B	mean
Viola arvensis L.	19.6	16.0	17.8	15.1	5.3	10.2	17.8	17.8	17.8	10.7	10.7	10.7	16.0	8.9	12.5	15.8	11.7	13.8
Echinochloa crus-galli (L.) P. Beauv.	12.4	10.7	11.6	7.1	7.1	7.1	23.1	8.9	16.0	14.2	14.2	14.2	12.4	14.2	13.3	13.8	11.0	12.4
Chenopodium album L.	14.2	14.2	14.2	9.8	7.1	8.5	8.0	8.9	8.5	14.2	8.9	11.6	5.3	5.3	5.3	10.3	8.9	9.6
Fallopia convolvulus (L.) Á. Löve	10.7	7.1	8.9	9.8	3.6	6.7	7.1	5.3	6.2	7.1	3.6	5.4	0.0	3.6	1.8	6.9	4.6	5.8
Tripleurospermum maritimum L.	24.9	3.6	14.3	1.8	1.8	1.8	0.0	3.6	1.8	8.9	3.6	6.3	8.9	0.0	4.5	8.9	2.5	5.7
Stellaria media (L.) Vill.	10.7	1.8	6.3	5.3	0.0	2.7	0.0	0.0	0.0	12.4	5.3	8.9	7.1	3.6	5.4	7.1	2.1	4.6
Erodium cicutarium (L.) L. Her.	1.8	5.3	3.6	1.8	0.0	0.9	5.3	5.3	5.3	1.8	3.6	2.7	3.6	3.6	3.6	2.9	3.6	3.3
Capsella bursa-pastoris (L.) Med.	7.1	3.6	5.4	0.0	1.8	0.9	5.3	1.8	3.6	1.8	3.6	2.7	0.0	0.0	0.0	2.8	2.2	2.5
Setaria viridis (L.) P. Beauv.	5.3	3.6	4.5	0.0	0.0	0.0	0.0	1.8	0.9	0.0	3.6	1.8	5.3	1.8	3.6	2.1	2.2	2.2
Anthemis arvensis L.	0.0	1.8	0.9	0.0	0.0	0.0	0.0	1.8	0.9	8.9	0.0	4.5	7.1	0.0	3.6	3.2	0.7	2.0
Amaranthus retroflexus L.	0.0	5.3	2.7	3.6	0.0	1.8	0.0	0.0	0.0	10.7	0.0	5.4	0.0	0.0	0.0	2.9	1.1	2.0
Veronica arvensis L.	7.1	1.8	4.5	1.8	0.0	0.9	1.8	1.8	1.8	0.0	0.0	0.0	0.0	1.8	0.9	2.1	1.1	1.6
Fagopyrum esculentum Moench.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	1.8	0.0	5.3	2.7	0.7	1.1	0.9
Centaurea cyanus L.	1.8	0.0	0.9	0.0	3.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.6
Myosotis arvensis (L.) Hill.	0.0	0.0	0.0	0.0	1.8	0.9	0.0	1.8	0.9	0.0	1.8	0.9	0.0	0.0	0.0	0.0	1.1	0.6
Geranium pusillum L.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.4	0.2
Number of annual species	12	12	14	10	8	13	7	11	11	12	11	15	8	9	11	15	16	17
Elymus repens (L.) Gould.	10.7	5.3	8.0	13.3	12.4	12.9	11.6	8.9	10.3	14.2	5.3	9.8	10.7	7.1	8.9	12.1	7.8	10.0
Equisetum arvense L.	0.0	3.6	1.8	0.0	5.3	2.7	8.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.8	1.7
Artemisia vulgaris L.	3.6	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.4
Number of perennial species	2	2	3	1	2	2	2	1	2	1	1	1	1	1	1	3	2	3
Total number of species	14	14	17	11	10	15	9	12	13	13	12	16	9	10	12	18	18	20

*without cover; **under polypropylene fibre

Table 5. Number of weeds (plant/m²) after cover removal (the mean for 2010–2012)

Kind of straw mulch	Cultivation		The mean
	without cover	under polypropylene fibre	
broccoli			
The control	231.1	392.9	312.0
Rye	69.3	176.0	122.7
Corn	133.3	254.2	193.8
Rape	124.4	243.6	184.0
Buckwheat	56.9	144.0	100.4
The mean	123.0	242.1	182.6
LSD (0,05) for: cultivation = 64.3; kind of straw mulch = 41.5; cultivation × kind of straw mulch = 43.4			
tomato			
The control	136.0	192.9	164.4
Rye	58.7	123.6	91.1
Corn	87.1	151.1	119.1
Rape	104.0	197.3	150.7
Buckwheat	110.2	163.6	136.9
The mean	99.2	165.7	132.4
LSD (0,05) for: cultivation = 15.6; kind of straw mulch = 34.8; cultivation × kind of straw mulch = 22.2			

Table 6. Number of weeds (plant/m²) before vegetable harvest (the mean for 2010–2012)

Kind of straw mulch	Cultivation		The mean
	without cover	under polypropylene fibre	
broccoli			
The control	99.6	96.0	97.8
Rye	93.3	60.4	76.9
Corn	94.2	72.9	83.6
Rape	92.4	60.4	76.4
Buckwheat	78.2	62.2	70.2
The mean	91.6	70.4	81.0
LSD (0,05) for: cultivation = 15.9; kind of straw mulch = 18.7; cultivation × kind of straw mulch = 15.9			
tomato			
The control	131.6	83.6	107.6
Rye	73.8	49.8	61.8
Corn	88.0	67.6	77.8
Rape	110.2	65.8	88.0
Buckwheat	76.4	55.1	65.8
The mean	96.0	64.4	80.2
LSD (0,05) for: cultivation = 18.7; kind of straw mulch = 19.7; cultivation × kind of straw mulch = 12.2			

ly fewer weeds found in plots mulched with buckwheat straw compared to corn straw, and the control without mulch. The differences amounted to 16.0 and 21.4 no./m², respectively. However, in the cultivation taking place under cover, organic mulch – irrespective of the type, contributed significantly to a decrease in the number of weeds compared to the control plot.

In tomato cultivation, all types of mulch significantly decreased the number of weeds. Both in the plots without cover and the plots covered with polypropylene fibre, the most effective for limiting the weed infestation was rye and buckwheat straw. Mulch with rape straw had less influence on reducing the number of weeds. The results of our study indicated that the type of mulch had a significant influence on the number of weeds suppressed, which may be due to the allelopathic effects of straw on the germination of individual species. Teasdale and Mohler (2000) and Vidal and Baumann (1994) claim that weed suppression can result from the mulch layer's ability to liberate substances inhibiting the development of some weed species. This is confirmed in the study by Creamer *et al*. (1996). According to the author's cover crop, residues remaining on the soil surface can physically modify seed germination by altering the seed environment (changes in light availability, soil temperatures, and soil moistures) and through other types of interference, primarily allelopathy.

The effect of covering and mulching on fresh weed masses

An interaction of the investigated factors had a significant influence on the fresh mass of weeds in broccoli and tomato cultivation immediately after cover removal (Table 7). The study results showed that covering the plants with polypropylene fibre caused an increase in the fresh mass of weeds, on average, by 198.0 g/m^2 in broccoli and 244.8 g/m^2 in tomato cultivation. An increased, mass of weeds as a result of covering was confirmed in the study by Peakock (1991). However, in the study by Pszczółkowski (2003b), the fresh mass of weeds from plots covered with perforated foil and polypropylene fibre, as well as the control without a cover, did not differ significantly.

In broccoli cultivation without a cover, there were significantly fewer fresh masses of weeds found in plots mulched with rye, corn, and buckwheat straw, compared to the control without mulch. The fresh mass of weeds on the rape straw mulch was also lower than in the control plot but the difference was not statistically confirmed. In the covered plots, all types of mulch contributed to a significant decrease in weed mass compared to the control plot which had no mulching. An application of rye and buckwheat straw significantly decreased the weed mass compared to that found on the mulch with corn and buckwheat straw, compared to rape straw.

In tomato cultivation, both in combination with cover and without cover, a significantly lower mass characterised weeds from rye and buckwheat straw compared to the remaining type of mulch, and the control which did not have mulch. In cultivation under cover, it was also found that weeds from mulch with corn straw were characterised by a lower mass than the mass of weeds from rape.

Before the broccoli harvest, plant coverings and the type of mulch had a significant influence on the fresh mass of weeds (Table 8). The study results indicated that weeds from the cultivation of the vegetables under cover, were characterised as having a significantly lower fresh mass. The difference, compared to the mass of weeds from plots without a cover, amounted to 219.4 g/m^2. It was also found that mulch with buckwheat straw was the most effective. Weeds from plots mulched with rye straw were also characterised as having a significantly lower fresh mass, compared to the control plot. The mass of weeds from plots mulched with corn and rape straw was lower than in the control but the difference was not statistically confirmed.

Before the tomato fruit was harvested, the type of mulch applied to the soil had a significant influence on the mass of weeds. It was found that all the types of mulch contributed to a decrease in the mean mass of weeds, compared to the control plot without mulch. Mulch with rye and buckwheat straw reduced the mass of weeds compared to rape straw mulch. This was confirmed in the study by Zaniewicz-Bajkowska *et al*. (2009), in which straw mulch left on the field till cabbage harvest, significantly reduced the fresh mass of weeds, on average, by 38.8% compared to the control without mulch. In the study by Din *et al*. (2013), soil mulching with wheat straw in corn cultivation contributed to a decreased mass of weeds, on average, by 27.1%, compared to the plot without straw. In the study by Duppong *et al*. (2004), mulch with oat straw caused a significant decrease in the mass of weeds compared to the control. In turn, Ahmed *et al*. (2007) claimed that mulch with wheat straw contributed to a significant decrease in the mass of weeds, compared to the control, however, higher rates of mulch application controlled weeds more effectively. A trend showing a gradual decrease in weed biomass when there was an increase in the mulch rate, was observed. This is confirmed in the study by Uwah and Iwo (2011), in which there was a decrease in the mass of weeds when there was an increase in the grass dose applied to soil mulching. The most weeds with the highest mass was found in the control plot which did not receive mulch. Also in the study by Zarea *et al*. (2010), the greater total crop biomass caused higher weed suppression.

Table 7. Fresh mass of weeds (g/m^2) after cover removal (the mean for 2010–2012)

Kind of straw mulch	Cultivation		The mean
	without cover	under polypropylene fibre	
broccoli			
The control	226.1	638.7	432.4
Rye	53.3	170.7	112.0
Corn	87.0	332.3	209.7
Rape	136.2	279.0	207.6
Buckwheat	32.9	104.9	68.9
The mean	107.1	305.1	206.1
LSD (0,05) for: cultivation = 165.6; kind of straw mulch = 79.1; cultivation × kind of straw mulch = 133.5			
tomato			
The control	609.8	898.8	754.3
Rye	96.9	357.3	227.1
Corn	460.1	581.3	520.7
Rape	380.4	742.3	561.4
Buckwheat	151.7	343.2	247.4
The mean	339.8	584.6	462.2
LSD (0,05) for: cultivation = 109.6; kind of straw mulch = 203.7; cultivation × kind of straw mulch = 152.2			

Table 8. Fresh mass of weeds (g/m^2) before vegetable harvest (the mean for 2010–2012)

Kind of straw mulch	Cultivation		The mean
	without cover	under polypropylene fibre	
broccoli			
The control	1,170.3	901.7	1,036.0
Rye	976.0	621.0	798.5
Corn	1,091.6	800.9	946.2
Rape	835.8	847.1	841.4
Buckwheat	714.7	520.9	617.8
The mean	957.7	738.3	848.0
LSD (0,05) for: cultivation = 218.7; kind of straw mulch = 219.4; cultivation × kind of straw mulch = ns			
tomato			
The control	1,554.1	1,126.3	1,340.2
Rye	782.3	350.1	566.2
Corn	935.7	592.0	763.8
Rape	1,149.4	787.6	968.5
Buckwheat	675.6	590.6	633.1
The mean	1,019.4	689.3	854.4
LSD (0,05) for: cultivation = ns; kind of straw mulch = 328.1; cultivation × kind of straw mulch = ns			

Conclusions

The investigated experimental factors influenced the species composition, number, and fresh weed mass. In both estimation dates (after cover removal and before the vegetables harvest), there were 24 and 25 noted weeds species, respectively, mostly characteristic for vegetable crops. The dominant species among the annuals were *Ch. album*, *E. crus-galli*, *V. arvensis*, however, among the perennials, the most common weed was *E. repens*. The abundant infestation and also the presence of a few perennial species could be due to the low dose of straw applied in the soil mulching process. The application of a polypropylene fibre cover caused an increased weed infestation in the initial period of vegetable growth, compared with plots without a cover. The increase in air and soil temperature, and moisture under polypropylene fibre covers provide good conditions for growth and development of not only crop plants but also weeds. This is why there is a higher crop infestation in covered plots. However, before vegetable harvest, a decrease was found in the number and fresh mass of weeds in the covered plots. Lower infestation on the covered plots was due to the fast rate of crop plant growth and higher possibilities to compete with weeds compared to those plants not under a cover. The results showed that all types of mulch caused a decrease in weed infestation, compared to the control plot which did not receive mulch. The most efficient for limiting infestation was mulch with buckwheat and rye straw.

Acknowledgements

The research was supported by the Polish Ministry of Science and Higher Education as part of the statutory activities of the Department of Vegetable Crops, Siedlce University of Natural Sciences and Humanities.

References

Ahmed Z.I., Ansar M., Iqbal M., Minhas N.M. 2007. Effect of planting geometry and mulching on moisture conservation, weed control and wheat growth under rainfed conditions. Pak. J. Bot. 39 (4): 1189–1195.

Anyszka Z., Dobrzański A. 2008. Zmiany w zachwaszczeniu pora z rozsady pod wpływem ściółki organicznej. [Changes in weed infestation in transplanted leek grown in organic mulch]. Prog. Plant Prot./Post. Ochr. Roślin 48 (4): 1391–1395.

Bàrberi P. 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Res. 42 (3): 177–193.

Bittencourt H.H., Lovato P.E., Comin J.J., Lana M.A., Altieri M.A., Costa M.D., Gomes J.C. 2013. Effect of winter cover crop biomass on summer weed emergence and biomass production. J. Plant Prot. Res. 53 (3): 248–252.

Campiglia E., Mancinelli R., Radicetti E., Caporali F. 2010. Effect of cover crops and mulches on weed control and nitrogen fertilization in tomato (*Lycopersicon esculentum* Mill.). Crop Prot. 29 (4): 354–363.

Cardina J., Regnier E., Harrison K. 1991. Long-term tillage effects of seed banks in three Ohio soils. Weed Sci. 39 (2): 186–194.

Creamer N.G., Bennett M.A., Stinner B.R., Cardina J., Regnier E.E. 1996. Mechanisms of weed suppression in cover crop-based production systems. Hort. Sci. 31 (3): 410–413.

Din S., Ramzan M., Khan R., Rahman M., Haroon M., Khan T.A., Samad A. 2013. Impact of tillage and mulching practices on weed biomass and yield components of maize under rainfed condition. Pak. J. Weed Sci. Res. 19 (2): 201–208.

Döring T.F., Brandt M., Heß J., Finckh M.R., Saucke H. 2005. Effect of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. Field Crop Res. 94 (2–3): 238–249.

Duppong L.M., Delate K., Liebman M., Horton R., Romero F., Kraus G., Petrich J., Chowdbury P.K. 2004. The effect of natural mulches on crop performance, weed suppression

and biochemical constituents of Cantip and St. John's Wort. Crop Sci. 44 (3): 861–869.

Economou G.O., Tzakou A., Gani A., Yannitsaros A., Bilalis D. 2002. Allelopathic effect of *Conyza albida* on *Avena sativa* and *Spirodela polyrhiz*. J. Agron. Crop Sci. 188 (4): 248–253.

Grassbaugh E.M., Regnier E.E., Bennett M.A. 2004. Comparison of organic and inorganic mulches for heirloom tomato production. Acta Hort. 638: 171–176.

Hembry J.K., Davies J.S. 1994. Using mulches for weed control and preventing leaching of nitrogen fertilizer. Acta Hort. 371: 311–316.

Jodaugienė D., Pupalienė R., Urbonienė M., Pranckietis V., Pranckietienė I. 2006. The impact of different types of organic mulches on weed emergence. Agron. Res. 4 (Special issue): 197–201.

Klümper H., Gerhards R., Kühbauch X. 1996. Einfluss des Lichtes auf die Keimung von Unkrauten. Zeitung für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft 15: 71–73.

Liebman M., Davis A.S. 2000. Integration of soil, crop and weed management in low-external-input farming system. Weed Res. 40 (1): 27–47.

Mohler C.L., Teasdale J.R. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. Weed Res. 33 (6): 487–499.

Mohtisham A., Ahmad R., Ahmad Z., Aslam M.R. 2013. Effect of different mulches techniques on weed infestation in aerobic rice (*Oryza sativa* L.). Am.-Eur. J. Agric. Environ. Sci. 13 (2): 153–157.

Peakock L. 1991. Effect of weed growth of short term cover over organically grown carrots. Biol. Agric. Hort. 7 (3): 271–279.

Petersen J., Röver A. 2005. Comparison of sugar beet cropping systems with dead and living mulch using a glyphosate – resistant hybrid. J. Agron. Crop Sci. 191 (1): 1–80.

Pszczółkowski P. 2003a. The attempts to control weed infestation in potatoes cultivated under shields. Part I. Plant response to herbicides. Biul. IHAR 228: 249–260.

Pszczółkowski P. 2003b. The attempts to control weed infestation in potatoes cultivated under shields. Part II. Mass, population and species composition of weeds. Biul. IHAR 228: 261–273.

Radics L., Szné Bognár E. 2004. Comparison of different mulching methods for weed control in organic green bean and tomato. Acta Hort. 638: 189–196.

Ramakrishna A., Hoang M.T., Wani S.P., Tranh D.L. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crop Res. 95 (2–3): 115–125.

Rogers G.S., Little S.A., Silcock S.J., Williams L.F. 2004. No-till vegetable production using organic mulches. Acta Hort. 638: 215–223.

Roztropowicz S., Lutomirska B. 1997. Technologia produkcji ziemniaka na wczesny zbiór. p. 82–98. W: „Produkcja ziemniaków. Technologia-Ekonomika-Marketing". [Technology of potato production for early harvest. In: "Potato Production. Technology-Economics-Marketing"] (J. Chotkowski, ed.). IHAR, Bonin, Poland, 299 pp.

Sinkevičienė A., Jodaugienė D., Pupalienė R., Urbonienė M. 2009. The influence of organic mulches on soil properties and crop yield. Agron. Res. 7 (1): 485–491.

Smeda R.J., Weller S.C. 1996. Potential of rye (*Secale cereale*) for weed management in transplant tomatoes (*Lycopersicon esculentum*). Weed Sci. 44 (3): 596–602.

Teasdale J.R., Moher C.L. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48 (3): 385–392.

Uwah D.F., Iwo G.A. 2011. Effectiveness of organic mulch on the productivity of maize (*Zea mays* L.) and weed growth. J. Anim. Plant Sci. 21 (3): 525–530.

Vidal R.A., Baumann T.T. 1994. Straw density in no-till affects soybean-weeds interference. p. 268–269. In: Proc. 3rd European Sociological Association (ESA) Congress, Padova, Italy, 18–22 September 1994.

Weber R., Hryńczuk B. 2005. Influence of forecrop and mode of tillage on weed infestation of winter wheat. Ann. UMCS, Sec. E, Vol. LX, 60: 93-102.

Wierzbicka B. 1995. Studia nad przyśpieszoną uprawą wczesnych odmian ziemniaka. [Study above accelerated cultivation of early potato cultivars]. Habilitation thesis, Zesz. Nauk. Akademii Rolniczo-Technicznej w Olsztynie, Agricultura 61: 1–46.

World Reference Base for Soil Resources 1998. World Soil Resource Reports Food and Agriculture Organization (FAO), International Soil Reference and Information Centre (ISRIC), International Society for the Systems Sciences (ISSS), Rome, p. 103–115.

Yordanova M., Shaban N. 2007. Effect of mulching on weeds of fall broccoli. Bull. Univ. Agric. Sci. Veterinary Medicine Cluj-Napoca 64 (1–2): 99–102.

Zagaroza C. 2003. Weed management in vegetables. Food and Agriculture Organization of the United Nations. FAO Plant Production and Protection 120: 1.

Zaniewicz-Bajkowska A., Franczuk J., Kosterna E. 2009. Direct and secondary effect of soil mulching with straw on the fresh mass and number of weeds and vegetable yield. Polish J. Environ. Stud. 18 (6): 1183–1188.

Zarea M.J., Ghalavand A., Goltapeh E.M., Rejali F. 2010. Effect of clovers intercropping and earthworm activity on weed growth. J. Plant Prot. Res. 50 (4): 463–469.

Zarzecka K., Gąsiorowska B. 2001. Wpływ metod pielęgnacji na zachwaszczenie i plonowanie ziemniaka. [The effect of weed control methods on the infestation and potato yields]. Zesz. Nauk. Akademii Podlaskiej w Siedlcach, Ser. Rolnictwo 59: 15–25.

Zarzecka K., Gugała M. 2005. Population and species composition of weed under differentiated conditions of weed control method. Acta Agrobot. 58 (1): 291–302.